

DISTORTION REDUCTION IN A WIRELESS COMMUNICATION DEVICE

BACKGROUND

Field of the Invention

[0001] The present invention is related generally to wireless communication devices, and, more particularly, to a system and method for distortion reduction in a wireless communication device.

Description of the Related Art

[0002] The present invention provides this, and other advantages, as will be apparent from the following detailed description and the accompanying figures.

[0003] Wireless communication systems are proliferating as more and more service providers add additional features and technical capabilities. A large number of service providers now occupy a relatively limited portion of the radio frequency spectrum. Due to this crowding, increased interference between wireless communication systems is commonplace. For example, wireless communication systems from two different service providers may occupy adjacent portions of the spectrum. In this situation, interference may be likely.

[0004] One example of such interference occurs in a code division multiple access (CDMA) wireless system. In one embodiment, a CDMA system occupies a portion of the frequency spectrum adjacent to a portion of the frequency spectrum allocated to a conventional cellular telephone

system, sometimes referred to as an advanced mobile phone system (AMPS).

[0005] Conventional CDMA units attempt to eliminate undesirable signals by adding filters following the mixer stage. FIG. 1 illustrates one known implementation of a direct-to-baseband or low IF wireless system 10 in which a radio frequency (RF) stage 12 is coupled to an antenna 14. The output of the RF stage 12 is coupled to an amplifier 16, which amplifies the radio frequency signals. It should be noted that the RF stage 12 and the amplifier 16 may include conventional components such as amplifiers, filters, and the like. The operation of these stages is well known and need not be described in greater detail herein.

[0006] The output of the amplifier 16 is coupled to a splitter 18 that splits the processed signal into two identical signals for additional processing by a mixer 20. The splitter 18 may be an electronic circuit or, in its simplest form, just a wire connection. The mixer 20 comprises first and second mixer cores 22 and 24, respectively. The mixers 22 and 24 are identical in nature, but receive different local oscillator signals. The mixer core 22 receives a local oscillator signal, designated LOI, while the mixer core 24 receives a local oscillator signal, designated as LOQ. The local oscillator signals are 90° out of phase with respect to each other, thus forming a quadrature mixer core. The output of the mixer 20 is coupled to jammer rejection filter stage 26. Specifically, the output of the mixer core 22 is coupled to a jammer rejection filter 28 while the output of the mixer core 24 is coupled to a jammer rejection filter 30. The operation of the jammer rejection filters 28 and 30 is identical except for the quadrature phase relationship of signals from the mixer 20. The output

of the jammer rejection filters 28 and 30 are the quadrature output signals I_{OUT} and Q_{OUT} respectively.

[0007] The jammer rejection filters 28 and 38 are designed to remove unwanted signals, such as signals from transmitters operating at frequencies near the frequency of operation of the system 10. Thus, the jammer rejection filters 28 and 30 are designed to remove "out-of-band" signals. In operation, the jammer rejection filters 28 and 30 may be lowpass filters, bandpass filters, or complex filters (e.g., a single filter with two inputs and two outputs), depending on the implementation of the system 10. The operation of the jammer rejection filters 28 and 30 are well known in the art and need not be described in greater detail herein. While the jammer rejection filters 28 and 30 may minimize the effects of out-of-band signals, there are other forms of interference for which the jammer rejection filters are ineffective.

[0008] For example, distortion products created by the mixer 20 may result in interference that may not be removed by the jammer rejection filters 28 and 30. If one considers a single CDMA wireless unit, that unit is assigned a specific radio frequency or channel in the frequency spectrum. If an AMPS system is operating on multiple channels spaced apart from each other by a frequency $\Delta\omega$, then the second-order distortion from the mixer 20 will create a component at a frequency $\Delta\omega$ in the output signal. It should be noted that the second order distortion from the mixer 20 will create signal components at the sum and difference of the two jammer frequencies. However, the signal resulting from the sum of the jammer frequencies is well beyond the operational frequency of the wireless device and thus does not cause interference. However, the difference signal, designated herein as $\Delta\omega$,

may well be inside the desired channel and thus cause significant interference with the desired signal.

[0009] In this circumstance, the AMPS signals are considered a jammer signals since they create interference and therefore jam the desirable CDMA signal. Although the present example refers to AMPS signals as jammer signals, those skilled in the art will appreciate that any other radio frequency sources spaced at a frequency of $\Delta\omega$, from each other may be considered a jammer.

[0010] If this second-order distortion signal is inside the channel bandwidth, the jammer rejection filters 28 and 30 will be ineffective and the resultant interference may cause an unacceptable loss of carrier-to-noise ratio. It should be noted that this interference may occur regardless of the absolute frequencies of the jammer signals. Only the frequency separation is important if the second-order distortion results in the introduction of an undesirable signal into the channel bandwidth of the CDMA unit.

[0011] Industry standards exist that specify the level of higher order distortion that is permitted in wireless communication systems. A common measurement technique used to measure linearity is referred to as an input-referenced intercept point (IIP). The second order distortion, referred to as IIP2, indicates the intercept point at which the output power in the second order signal intercepts the first order signal. As is known in the art, the first order or primary response may be plotted on a graph as the power out (P_{out}) versus power in (P_{in}). In a linear system, the first order response is linear. That is, the first order power response has a 1:1 slope in a log-log plot. The power of a second order distortion product follows a 2:1 slope on a log-log plot. It follows that the

extrapolation of the second order curve will intersect the extrapolation of the fundamental or linear plot. That point of intercept is referred to as the IIP2. It is desirable that the IIP2 number be as large as possible. Specifications and industry standards for IIP2 values may vary from one wireless communication system to another and may change over time. The specific value for IIP2 need not be discussed herein.

[0012]

It should be noted that the second-order distortion discussed herein is a more serious problem using the direct down-conversion architecture illustrated in FIG. 1. In a conventional super-heterodyne receiver, the RF stage 12 is coupled to an intermediate frequency (IF) stage (not shown). The IF stage includes bandpass filters that readily remove the low frequency distortion products. Thus, second-order distortion is not a serious problem with a super-heterodyne receiver. Therefore, the IIP2 specification for a super-heterodyne receiver is generally not difficult to achieve. However, with the direct down-conversion receiver, such as illustrated in FIG. 1, any filtering must be done at the baseband frequency. Since the second-order distortion products at the frequency separation, $\Delta\omega$, regardless of the absolute frequency of the jammers, the IIP2 requirements are typically very high for a direct-conversion receiver architecture. The IIP2 requirement is often the single most difficult parameter to achieve in a direct down-conversion receiver architecture.

[0013]

As noted above, the second-order distortion is often a result of non-linearities in the mixer 20. There are a number of factors that lead to imbalances in the mixer 20, such as device mismatches (e.g., mismatches in the mixer cores 22 and 24), impedance of the local oscillators, and impedance mismatch. In addition, factors such as the

duty cycle of the local oscillator also has a strong influence on the second-order distortion. While various calibration schemes may be effective to reestablish symmetry in the mixer 20, this calibration is time-consuming and will vary from one wireless unit to the next due to component variations. Such time-consuming calibration processes are expensive do not lend themselves well to high-volume production since the calibration must be done initially at the factory and may require periodic recalibration during normal use.

[0014] In addition to the calibration difficulties, the undesirable second-order products are generally quite low relative to the desired signal and are thus not directly measurable. All these factors lead to difficulty in reducing the second-order distortion products to an acceptable level. Therefore, it can be appreciated that there is a significant need for a system and method for wireless communication that reduces the undesirable distortion products to an acceptable level. The present invention provides this and other advantages as will be apparent from the following detailed description and accompanying figures.

BRIEF SUMMARY

[0015] The present invention is embodied in a system and method for the reduction of distortion in a wireless communication circuit. The wireless communication circuit has a combined signal that includes a desired signal and a jammer signal. The system comprises a filter to remove the desired signal and thereby provide a filtered signal representative of the jammer signal and an adder circuit that receives the

combined signal and the filtered signal to thereby remove the jammer signal.

[0016] The system may be implemented using a feedback approach or a feedforward approach. In the feedback implementation, a radio receiver receives the radio frequency signal at a selected radio frequency. The received RF signal contains the desired signal and the jammer signal. A mixer core converts the received RF signal to a selected lower frequency. The filter operates at the selected lower frequency to remove the desired signal. An up-mixer is coupled to the filter to convert the filtered signal to the selected radio frequency. The adder operates at the radio frequency to remove the jammer signal from the combined radio frequency signal.

[0017] In the feedforward system a conventional radio receiver receives the radio frequency signal at a selected radio frequency. The received RF signal contains both the desired signal and the jammer signal. A conventional mixer core converts the received RF signal to a selected processing frequency. In this implementation, the invention comprises a down-mixer to convert the received RF signal to a selected lower frequency with the filter operating at the selected lower frequency to remove the desired signal. The system further comprises an up-mixer coupled to the filter to convert the filtered signal to the selected radio frequency. The adder operates at the selected radio frequency to remove the jammer signal and generate an output signal that is coupled to the mixer core. In this manner, the undesirable jammer signal is eliminated prior to processing by the mixer core.

[0018] Both the feedback and feedforward implementations may be implemented in a quadrature system. In a quadrature implementation,

the filter is implemented as first and second filter portions that generate first and second quadrature components, respectively. In the feedback system, the up-mixer comprises first and second quadrature up-mixers to convert the first and second filtered signal portions to the selected radio frequency. The quadrature system also includes a summer coupled to the first and second quadrature up-mixer portions to combine the converted first and second signal portions.

[0019]

In a quadrature implementation of the feedforward system, the down-mixers comprise first and second down-mixer portions to convert the received radio frequency signal to first and second quadrature components at the selected lower frequency. The first and second filter portions filter the first and second quadrature components and the up-mixer comprises first and second up-mixer portions to convert the first and second filtered quadrature signal portions to the selected radio frequency. The system also includes a summer coupled to the first and second quadrature up-mixer portions to combine the converted first and second signal portions.

[0020]

In one implementation, the filter operates at baseband frequencies to allow direct conversion from the selected radio frequency to baseband. The filters may be implemented as analog filters. In one implementation, the filter is a high-pass filter. The wireless communication unit has the specified operational bandwidth and the filter bandwidth may be based on the operational bandwidth.

BRIEF DESCRIPTION OF THE DRAWINGS

- [0021] FIG. 1 is a functional block diagram of a conventional wireless communication receiver.
- [0022] FIG. 2 is a functional block diagram of a generic implementation of the present invention.
- [0023] FIG. 3 is a functional block diagram of one implementation of the receiver of the present invention.
- [0024] FIG. 4 is a more detailed functional block diagram illustrating the operational characteristics of the system of FIG. 3.
- [0025] FIG. 5 is a functional block diagram of an alternative implementation of the present invention.
- [0026] FIG. 6 is a more detailed functional block diagram illustrating the operational characteristics of the system of FIG. 5.

DETAILED DESCRIPTION
OF THE EMBODIMENTS

- [0027] The present invention is directed to a system architecture that actively cancels out the undesirable portions of the signals, which may be referred to herein as jammer signals. Although different implementations may be used, the underlying principle is best illustrated in the functional block diagram of FIG. 2 where a system **100** implements the present invention. The RF stage **12** and antenna **14** are conventional components that need not be described in greater detail herein. A filter **102** having a filter function $F(s)$ serves to remove the desirable

portion of the received signal. Details of the filter 102 will be provided below.

[0028] The output of the filter 102 is the undesirable jammer signal. The output of the filter 102 (*i.e.*, the jammer signal) is combined with the output of the RF stage 12 by an adder 104. A positive input of the adder 104 is coupled to the output of the RF stage 12 while a negative input of the adder is coupled to the output of the filter 102. The adder 104 functions as a differential circuit and canals the undesirable signal that is present at both the positive input and the negative input of the adder. The output of the adder 104 contains only the desirable signal and thus the undesirable jammer signal has been effectively removed.

[0029] The system 100 may be implemented in a feedback mode, illustrated in the function block diagram of FIG. 3, or in a feedforward mode as illustrated in the function block diagram of FIG. 5. In the feedback embodiment of the system 100, the undesirable signal from jammers is canceled out using a feedback circuit 108. In the feedforward embodiment, illustrated in the functional block diagram of FIG. 5, the undesirable signal from jammers is canceled out using a feedforward circuit 118.

[0030] With reference to FIG. 3, a simplified functional block diagram of the system 100 models the signal response to permit the filter characteristics to be determined. The implementation illustrated in FIG. 3 includes the RF stage 12 and the antenna 14, which operate in a conventional manner. The output of the RF stage is a signal designated herein as i_{REF} , which coupled to the input of the adder 110. The output of the adder 110, which is designated as i_{CORR} is coupled to the mixer 20. In

the small signal analysis, the mixer 20 has a transfer function designated as G_{DN} .

[0031] The output of the mixer 20 is coupled to a feedback filter 112. The feedback filter 112 provides a measure of jammer signals. The characteristics of the feedback filter 112 are derived below. The output of the feedback filter 112 is coupled to an up-mixer 114, which has a transfer characteristic designated as G_{up} . The output of the up-mixer 114 is coupled to the negative input of the adder 110 to subtract the effects of the jammers in front of the mixer 20. In this way, the jammers are effectively canceled before they enter the mixer 20.

[0032] FIG. 4 provides an example implementation of the feedback implementation of the system 100 shown in FIG. 3. The operation of the RF stage 12, antenna 14, and amplifier 16 operate in a known manner and need not be described in greater detail herein. The output of the amplifier 16, which contains both the desired signal and the jammers, is coupled to the positive input of the adder 110. The negative input of the adder 110 receives a signal from the feedback circuit 108 and contains a measure of the jammer only. That is, the desirable signal has been removed by the feedback filter 112. The output of the adder 110 is coupled to the splitter 18. As previously discussed, the splitter operates in a conventional manner to split the received signal into two identical signals for coupling to the quadrature elements of the mixer 20. One signal from the splitter 18 is coupled to the input of the mixer core 22, which also receives an input signal from a local oscillator designated as LOI. Similarly, the other signal from the splitter 18 is coupled to the input of the mixer core 24, which receives a local oscillator signal designated as LOQ. As is known in the art, the local oscillators LOI and LOQ have

identical frequencies, but are 90° out of phase with respect to each other thus producing quadrature outputs from the mixer cores **22** and **24**.

[0033] The output of the mixer core **22** is designated as I_{OUT} while the output of the mixer core **24** is designated as Q_{OUT} . These two signals are processed in a conventional manner to decode the signal received by the system. The additional data processing steps required to decode the transmitted signal are known in the art and need not be described in any detail herein.

[0034] The output signals from the mixer cores **22** and **24** are also each provided to feedback filters **112a** and **112b**, respectively. Each of the feedback filters **112a** and **112b** function in the manner illustrated in the simplified functional block diagram of FIG. 3, but for different quadrature components. FIG. 3 is a small signal model of the circuit operation wherein

$$\frac{V_{OUT}}{i_{RF}} = \frac{G_{DN}}{1 + G_{DN}G_{UP}F_B(s)}$$

wherein V_{OUT} is the output signal from the mixer **20** and i_{RF} is the baseband equivalent of the actual signal current from the RF stage **12**. The term G_{DN} and G_{UP} represent the transfer functions of the mixer **20** and the up-mixer **114**, respectively, while $F_B(s)$ is the Laplace transform representation of the feedback filter **112**.

[0035] The current i_{RF} is the baseband equivalent of the signal provided as the positive input to the adder **110** while the output signal from the adder **110** is shown as i_{CORE} which is a baseband equivalent of the actual signal from the adder **110** to the mixer **20**. The function of the adder **110** may be illustrated by the following:

$$\frac{i_{CORE}}{i_{RF}} = \frac{1}{1 + G_{DN}G_{UP}F_B(s)}$$

where all terms are previously defined. If $H(g)$ is the desired baseband filtering, then the transfer function of the filter may be represented by the following:

$$H(g) = \frac{1}{1 + G_{DN}G_{UP}F_B(s)}$$

where all terms have been previously defined.

[0036] It is desirable to make i_{CORE} much smaller than i_{RF} at the jammer frequencies. This can be accomplished by making the product $G_{DN}G_{UP}F_B(s)$ large at these jammer frequencies. At the desired receive frequencies, it is desirable to have the value $F_B(s) \rightarrow 0$. The resultant filter transfer characteristics of the feedback filters 112a and 112b remove the desired signal and thus provide a measure of the jammer signals. The feedback filters 112a and 112b may be implemented as conventional analog filters using known techniques. In an exemplary embodiment, the feedback filters 112 may be implemented as analog transconductance active high-pass filters whose cut-off frequency is selected to be half the channel bandwidth specified for the system 100. As those skilled in the art can appreciate, the system 100 is operating at a selected radio frequency and has a bandwidth determined by industry standards and regulatory bodies, such as the Federal Communications Commission (FCC). The specific radio frequency and channel bandwidth depend on the specific implementation.

[0037] Alternatively, the feedback filters 112a and 112b may be implemented digitally using, by way of example, a digital signal processor (not shown). Those skilled in the art can alter the system 100 to

accommodate various implementations of different radio frequencies and different channel bandwidths. In this manner, signals within the channel bandwidth are attenuated while signals outside the channel bandwidth, including jammer signals, are allowed to pass. Thus, the output signal from the feedback filter 112 is a measure of the jammer signal with the desired signal within the bandwidth having been removed by the filtering action. Returning again to FIG. 4, the outputs from the feedback filters 112 are coupled to the up-mixer 114. Specifically, the output of the feedback filter 112a is coupled to the input of an up-mixer 114a, which also receives a signal from the local oscillator LOI. Similarly, the output of the feedback filter 112b is coupled to the input of an up-mixer 114b, which also receives a signal from the local oscillator LOQ. The output of the up-mixers 114a and 114b are at the original radio frequency from the RF stage 12. The outputs of the up-mixers 114a and 114b are combined by a summer 130. The output of the summer 130 is provided as the feedback signal to the negative input of the adder 110. Thus, the feedback circuit comprising the feedback filter 112, up-mixer 114, and summer 130 provide a signal representative of the jammer signals. By coupling these signals to the negative input of the adder 110, the undesirable jammer signals are effectively removed from the combined signal containing the desired signal and the jammers. This effectively cancels the jammer signals before they enter the mixer 20.

[0038]

It should be noted that the second-order intermodulation products from the up-mixer 114 are non-critical in the present evaluation because they lie far away from the radio frequency at which the system 100 operates. It should be further noted that the embodiment illustrated in FIG. 4 uses a direct-to-baseband signal processing

technique, which eliminates the requirement of an IF stage. As previously noted, a super-heterodyne receiver using an IF stage includes bandpass filters that can be used to minimize the second order distortion. However, the system 100 can be applied to a receiver system having a low IF frequency. In this implementation, the high-pass filter functions of the feedback filter 112 are replaced with a somewhat more complex bandpass filter centered around the selected intermediate frequency.

FIG. 5 is a functional block diagram illustrating a feedforward technique for implementing the system 100. In this implementation, the output of the RF stage 12 is coupled to a down-mixer 120, which mixes the RF signal down to baseband or to some selected intermediate frequency. A feedforward filter 122 filters out the desired RF signal and thus provides a measure of the jammers. An up-mixer 124 mixes the measure of the jammer signal back to original radio frequency. The output of the up-mixer 124 is coupled to a negative input of an adder 126. The output of the RF stage, which contains both the desired signal and the jammer signal, is coupled to a positive input of the adder 126. The presence of the jammer signal at the negative input of the adder 126 effectively cancels out the contribution of the jammer signal. Thus, the output of the adder 126 contains only the desired signal. The output of the adder 126 is coupled to the mixer 20 for processing in the conventional manner. Thus, in both the feedback and feedforward approaches, the RF signal is a combination of the desired signal and the jammer signal. The combination signal is filtered to remove the desired signal and thereby provide a measure of the jammer signal. The jammer signal is coupled to the negative input of an adder to effectively remove the undesirable jammer signal from the combination signal.

[0040] An exemplary implementation of the feedforward embodiment of the system 100 is illustrated in the functional block diagram of FIG. 6. The RF stage 12, antenna 14, and amplifier 16 function in a conventional manner, as previously described. The output signal from the amplifier is coupled to a splitter 140. Although the splitter 140 operates in fundamentally the same fashion as the splitter 18 (see FIGS. 1 and 5), the splitter 140 receives the input signal i_{RF} and splits it into four signals. Two identical signals from the splitter 140 are routed to the feedforward circuit 118 while the remaining two signals from the splitter are routed to the mixer 20 via other circuit components that will be described in detail below.

[0041] The identical signals from the splitter 140 to the feedforward circuit 118 have a value of $\frac{\alpha}{2} \times i_{RF}$ where $\alpha \leq 1$. Thus, the signals provided to the feedforward circuit 118 are proportional to the input signal i_{RF} . The identical signals routed from the splitter 140 to the mixer 20 each have a value of $\frac{1-\alpha}{2} \times i_{RF}$.

[0042] The feedforward circuit 118 comprises the down-mixer 120, feedforward filter 122, and up-mixer 124. The signals $\frac{\alpha}{2} \times i_{RF}$ from the splitter 140 are coupled to the down-mixer 120. Specifically, one of the identical signals $\frac{\alpha}{2} \times i_{RF}$ from the splitter 140 is coupled to the input of a mixer 120a, which also receives a signal from the local oscillator LOI. Similarly, the other of the identical signals $\frac{\alpha}{2} \times i_{RF}$ from the splitter 140 is coupled to the input of a mixer 120b, which also receives a signal from the local oscillator LOQ. The output of the down-mixer 120a is coupled

to a feedforward filter **122a** while the output of the down-mixer **120b** is coupled to the input of a feedforward filter **122b**.

[0043] In an exemplary embodiment, the feedforward filters **122a** and **122b** are high-pass filters with a cutoff frequency selected to match half the channel bandwidth for the system **100**. As discussed above with respect to feedback circuit **108**, the feedforward filters **122** may be implemented as analog transconductance active high-pass filters. In the embodiment where the down-mixers **120** mix directly down to baseband, the feedforward filters **122** are high-pass filters having the characteristic described above. If the down-mixers are mixed to an intermediate frequency, the feedforward filters **122** may be somewhat more complex bandpass filters centered around the selected IF. Alternatively, the feedforward filters **122** may be implemented in digital form using, by way of example, a digital signal processor (not shown).

[0044] The output of the feedforward filter **122** is coupled to the up-mixer **124**. Specifically, the output of the feedforward filter **122a** is coupled to an input of an up-mixer **124a**, which also receives a signal from the local oscillator LOI. Similarly, the output of the feedforward filter **122b** is coupled to an input of an up-mixer **124b**, which also receives a signal from the local oscillator LOQ. The up-mixers **124a** and **124b** convert the filtered signal back to the original radio frequency. The outputs from the up-mixers **124a** and **124b** are combined by a summer **142** to thereby produce a signal representative of the jammers.

[0045] The output of the summer **142** is coupled to a splitter **144**. The splitter **144** operates in a conventional manner to split the combined signal from the summer **142** into two identical signals. Each of the identical signals will be routed to negative inputs of adders for

subsequent quadrature processing. Specifically, one of the identical signals from the splitter **144** is coupled to a negative input of an adder **146a**. The positive input of the adder **146a** receives a signal from the splitter **140** containing both the desired signal and the jammer signal. In contrast, the signal from the splitter **144** contains only the jammer signal, thus effectively canceling out the jammer signal from the combined signal and producing an output which contains only the desired signal.

[0046] Similarly, the other identical output signal from the splitter **144** is coupled to a negative input of an adder **146b**. The positive input of the adder **146b** receives a signal from the splitter **140** containing both the desirable signal and the jammer signal. In contrast, the signal from the splitter **144** contains only the jammer signal. The adder **146b** effectively cancels the effects of the jammer signal and produces an output containing only the desired signal.

[0047] The outputs from the adders **146a** and **146b** are coupled to the mixer **20**. Specifically, the output of the adder **146a** is coupled to an input of the mixer core **22**, which also receives a signal from the local oscillator LOI. The mixer core **22** produces the output signal I_{OUT} , which contains only the desired signal with the jammer signal having been effectively canceled by the adder **146a**.

[0048] Similarly, the output of the adder **146b** is coupled to an input of the mixer core **24**, which also receives a signal from the local oscillator LOQ. The output of the mixer core **24** is the output signal Q_{OUT} , which contains only the desired signal with the jammer signal having been effectively canceled by the adder **146b**. Thus, the jammer signals are effectively canceled before any processing by the mixer **20**. The clean

signals (*i.e.*, containing only the desirable signal) are provided from the outputs of the adders **146a** and **146b** to the mixer cores **22** and **24**, respectively. The mixer cores **22** and **24** operate in a conventional manner to produce the outputs I_{OUT} and Q_{OUT} . Subsequent processing of the clean signals occurs in a conventional manner that need not be described in greater detail herein.

[0049] The system **100** is thus capable of effectively canceling the undesirable jammer signals using a variety of system architectures. Although the system **100** is particularly useful for direct-to-baseband conversion, it may also be implemented in receiver systems with an IF stage. In the direct-to-baseband implementation, the system **100** provides significantly improved IIP2 performance. In a CDMA implementation, the IIP2 performance of the system **100** exceeds industry standards for IIP2.

[0050] Although the techniques described above improve the IIP2 response characteristics, it may also improve most other types of distortion. This is true because jammers are effectively removed from the mixer **20** and therefore any distortion products they might generate within the mixer are also removed. The distortion is thus largely determined by the up conversion mixers (*e.g.*, the mixer **114** of FIG. 4 and the mixer **124** of FIG. 6). In the case of even-order distortion (*e.g.*, the IIP2 distortion measurement), the up conversion mixers (*e.g.*, the mixers **114** and **124**) produce distortion products that are far away from the selected RF and thus cause no problem. In the case of odd-order distortion (*e.g.*, the IIP3 distortion measurement), the distortion products from the up conversion mixers will be close to the desired RF frequency and may fall inside the desired receive channel. However, those skilled in the art will

appreciate that up converters can usually be made more linear than down converters therefore a lower overall distortion can be achieved.

[0051] An additional advantage can be realized in the fact that the jammers at the output of the mixer 20 are greatly attenuated when compared with the output of the mixers in the known implementation illustrated in FIG. 1. As a result, it is possible to achieve much higher signal levels of the desired channel at the output of the mixer 20 since it is no longer necessary to accommodate high jammer levels at that point in the processing circuit. This, in turn, greatly reduces the necessary dynamic range of subsequent signal processing circuitry.

[0052] It is to be understood that even though various embodiments and advantages of the present invention has been set forth in the foregoing description, the above disclosure is illustrative only, and changes may be made in detail, yet remain within the broad principles of the invention. Therefore, the present invention is to be limited only by the appended claims.